

DescriptionMETHOD AND SYSTEM FOR CONTROLLING THE DUTY CYCLE OF A
CLOCK SIGNAL

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Technical Field

This invention relates to clock signal circuits, and more particularly to a method and system for controlling the duty cycle of an output clock signal independently of the duty cycle of an input clock signal.

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Background of the Invention

Clock signals are commonly used for a variety of purposes in digital systems, such as memory devices. For example, in a synchronous dynamic random access memory ("SDRAM"), a clock signal is used to determine the time at which control, data and address signals applied to the SDRAM are considered valid. The control, data and address signals are then latched into the SDRAM responsive to a transition of the clock signal.

In some cases, the duty cycle of the clock signal is not critical. For example, if the clock signal is used to latch a memory control signal once for each period of the clock signal, the control signal will be latched at the proper time regardless of whether the clock signal has a 50% duty cycle. However, controlling the duty cycle is critical in other applications. For example, in "double data rate" DRAMs, control, data and/or address signals are latched on each transition of the clock signal, *i.e.*, on both the rising and falling edges of the clock signals. If the clock signal does not have a 50% duty cycle, the latching of the signals will not be symmetrical, and the clock signal may therefore fail to properly latch the signals.

The duty cycle of a clock signal can become skewed, *i.e.*, vary from a 50% duty cycle, for a variety of reasons. For example, the clock signal may be coupled through a switching circuit that changes state when the clock signal has a predetermined voltage relative to the power supply voltage. In such case, power supply noise can momentarily increase or decrease the supply voltage, thereby altering the time at which the clock signal transitions. The duty of the clock signal can then vary

from cycle-to-cycle. In other cases, the components used in a circuit having a symmetrical topography do not have the same electrical characteristics, thus causing them to operate differently. For example, a first transistor used in the circuit may have a resistance or threshold voltage that is different from the resistance or threshold voltage of a second transistor used in the circuit. In such cases, the duty cycle will be constant from cycle-to-cycle, but the duty cycle will vary from 50%.

There is therefore a need for a system and method for controlling the duty cycle of a clock signal in a manner that is not affected by variations in power supply voltage or electrical characteristics of circuit components, so that a clock signal having a duty cycle of 50% or some other value can be generated.

Summary of the Invention

A method and system for generating an output clock signal having a controllable duty cycle from an input clock signal in accordance with the invention includes a duty cycle corrector circuit coupled to a duty cycle indicating circuit through a control circuit. The duty cycle corrector circuit is structured to transition the output clock signal to a first logic level responsive to a first transition of the input clock signal after a first delay that corresponds to a first control signal. The duty cycle corrector circuit is also structured to further transition the output clock signal to a second logic level that is different from the first logic level responsive to a second transition of the input clock signal that is different from the first transition of the input clock signal after a second delay that corresponds to a second control signal. The duty cycle indicating circuit is coupled to receive the output clock signal, and it generates a duty cycle feedback signal corresponding to the duty cycle of the output clock signal. The control circuit is structured to generate the first and second control signals as a function of the duty cycle feedback signal so that the first and second delays are selected to cause the output clock signal to have a predetermined duty cycle.

Brief Description of the Drawings

Figure 1 is a block diagram of a system for controlling the duty cycle of a clock signal according to an embodiment of the invention.

Figure 2 is a schematic of a duty cycle adjusting circuit according to an embodiment of the invention that is used in the system of Figure 1.

Figure 3 are timing diagrams showing the waveforms present in the duty cycle adjusting circuit of Figure 2.

5 Figure 4 is a schematic of an integrator circuit according to an embodiment of the invention that is used in the system of Figure 1.

Figure 5 is a schematic of a transconductance amplifier according to an embodiment of the invention that is used in the system of Figure 1.

10 Figure 6 is a schematic of a current mirror circuit according to an embodiment of the invention that is used in the system of Figure 1.

Figure 7 is a block diagram of an embodiment of a synchronous dynamic random access memory containing a system for controlling the duty cycle of a clock signal in accordance with the invention.

15 Figure 8 is a block diagram of a computer system using the SDRAM of Figure 7 including the duty cycle correction system of Figure 1.

Detailed Description of the Invention

One embodiment of a system 10 for controlling the duty cycle of a clock signal in accordance with the invention is illustrated in Figure 1. The system 10 includes a duty cycle adjustment circuit 12 that receives a clock signal CLK-IN and outputs a corresponding duty cycle adjusted output signal CLK-OUT. The adjustment circuit 12 also receives a pair of control signals V_P , V_N from a control circuit 14. As explained in greater detail below, the control signals V_P , V_N control the duration that the CLK-OUT signal is at two respective logic levels in order to control the duty cycle of the output signal CLK-OUT.

20 the output signal CLK-OUT.

The control circuit 14 generates the control signals V_P , V_N responsive to a pair of output signals I_1 , I_2 from a transconductance amplifier 16. The current of the output signals I_1 , I_2 produced by the transconductance amplifier is a function of the difference between a reference voltage V_{REF} and the magnitude of a feedback signal V_F from the output of an integrator 18. As explained in greater detail below, the feedback signal V_F from the integrator 18 is a function of the percent of time that the output signal CLK-OUT is at each of two logic levels, *i.e.*, the duty cycle. An increase in the

30 from the output of an integrator 18. As explained in greater detail below, the feedback signal V_F from the integrator 18 is a function of the percent of time that the output signal CLK-OUT is at each of two logic levels, *i.e.*, the duty cycle. An increase in the

duty cycle, *i.e.*, the time the output signal CLK-OUT is at a first logic level relative to the time that it is at a second logic level, causes the magnitude of the feedback signal V_F to increase. Conversely, a decrease in the duty cycle causes the magnitude of the feedback signal V_F to decrease.

5 The overall operation of the system 12 of Figure 1 will now be explained. The duty cycle adjustment circuit 12 outputs the CLK-OUT signal responsive to the CLK-IN signal. The integrator 18 receives the CLK-OUT signal and outputs the feedback signal V_F as a function of the duty cycle of the CLK-OUT signal. The transconductance amplifier 16 generates the output signals I_1 , I_2 in a manner
 10 causing that the sum of the current of output signals I_1 , I_2 to be constant. However, the difference between current of output signals I_1 , I_2 is a function of the difference between the magnitude of the feedback signal V_F and the magnitude of the reference voltage V_{REF} . As mentioned above, the output signals I_1 , I_2 cause the control circuit 14 to output corresponding control signals V_P , V_N , which control the duty cycle of the CLK-OUT
 15 output signal. As explained in greater detail below, the system 10 is substantially insensitive to variations in the magnitude of its power supply voltages, thus making the system less susceptible to noise jitter.

Although, the duty cycle of the CLK-OUT signal will generally be controlled so that it is substantially 50%, it will be understood that the system 10 is
 20 capable of setting the duty cycle to other values simply by varying the ratio I_P/I_N , as explained below with respect to Figure 4 magnitude of the reference voltage V_{REF} . The system 10 will automatically adjust the duty cycle of the CLK-OUT signal so that the magnitude of the feedback signal V_F from the integrator 18 approximately equals the magnitude of the reference voltage V_{REF} .

25 One embodiment of the duty cycle adjustment circuit 12 of Figure 1 is shown in Figure 2. The adjustment circuit 12 includes a series of two PMOS transistors 20, 22 and two NMOS transistors 30, 32 coupled between a supply voltage V_{CC} and ground. The gates of one of the PMOS transistors 20 and one of the NMOS transistors 30 are coupled to each other to receive the CLK-IN signal. As a result, the PMOS
 30 transistor 20 and the NMOS transistor 30 essentially function together as an inverter so that an output node 38 is coupled to ground when the CLK-IN signal is high and is coupled to the supply voltage V_{CC} when the CLK-IN signal is low.

The impedance between the supply voltage V_{CC} and the output node 38 is controlled by adjusting the level of the control signal V_P applied to the gate of the PMOS transistor 22. Similarly, the impedance between the output node 38 and ground is controlled by adjusting the level of the control signal V_N applied to the gate of the NMOS transistor 32.

The output node 38 is coupled to a capacitor 40 and to an input of an inverter 42. Therefore, when the PMOS transistor 20 is turned ON responsive to the CLK-IN signal being low, the capacitor 40 charges through the PMOS transistors 20, 22. Similarly, when the NMOS transistor 30 is turned ON responsive to the CLK-IN signal being high, the capacitor 40 discharges through the NMOS transistors 30, 32. The rate at which the capacitor 40 is charged and discharged is determined by the magnitude of the control signals V_P and V_N , respectively. When the capacitor 40 has been charged to a high transition voltage of the inverter 42, the output of the inverter transitions low. When the capacitor 40 has been discharged to a low transition voltage of the inverter 42, the output of the inverter transitions high. The output of the inverter 42 is coupled through a second inverter 44, which functions as a buffer, to generate the output signal CLK-OUT.

The duty cycle adjustment circuit 12 also includes a positive feedback PMOS transistor 46 and a positive feedback NMOS transistor 48. When the capacitor 40 has been discharged to the low transition voltage, the output of the inverter 42 transitions high, thereby turning ON the NMOS transistor 48. The ON impedance of the transistor 48 is substantially lower than the impedance of the NMOS transistor 32. As a result, turning the transistor 48 ON causes a substantial decrease in the impedance between the output node 38 and ground, thereby quickly discharging the capacitor 40. Similarly, when the capacitor 40 has been charged to the high transition voltage, the output of the inverter 42 transitions low, thereby turning ON the PMOS transistor 46. The ON impedance of the transistor 46 is substantially lower than the impedance of the PMOS transistor 22. As a result, turning the transistor 46 ON causes a substantial decrease in the impedance between the supply voltage V_{CC} and the output node 38, thereby quickly charging the capacitor 40. The positive feedback transistors 46, 48 ensure that the capacitor 40 is always charged from ground potential each time the CLK-IN transitions low, and is always discharged from ground potential each time the

CLK-IN transitions high. The resulting repeatability of the charge and discharge cycles ensures that the duty cycle of the CLK-OUT signal is accurately controlled by the control signals V_p and V_N .

The operation of the duty cycle adjustment circuit 12 will now be summarized with reference to the timing diagram of Figure 3. As shown therein, the CLK-IN signal has a duty cycle that is substantially greater than 50%. When the CLK-IN signal transitions high at time 815ns, the NMOS transistor 30 turns ON, thereby discharging the capacitor 40 through the NMOS transistors 30, 32. At time 832ns, when the voltage V_C on the capacitor 40 has been discharged to the lower transition voltage of the inverter 42, the output of the inverter 42 transitions high, thereby causing the CLK-OUT signal to transition low, as shown in Figure 3. The low-to-high transition of the inverter 42 output also turns ON the NMOS positive feedback transistor 48, thereby quickly discharging the capacitor 40. As a result, the voltage V_C on the capacitor 40 reaches ground potential and is maintained there well before the CLK-IN signal transitions low at time 850ns.

When the CLK-IN signal transitions low at time 850ns, the PMOS transistor 20 turns ON, thereby charging the capacitor 40 through the PMOS transistors 20, 22. At time 857ns, when the voltage V_C on the capacitor 40 has been charged to the higher transition voltage of the inverter 42, the output of the inverter 42 transitions low, thereby causing the CLK-OUT signal to transition high. The PMOS positive feedback transistor 46 is also turned ON at this time, thereby quickly charging the capacitor 40. As a result, the voltage V_C on the capacitor 40 reaches the supply voltage V_{CC} and is maintained there until the CLK-IN signal transitions high at time 865ns.

Notice that the capacitor 40 is discharged at a rate that is substantially slower than the rate at which the capacitor 40 is charged. As a result, the duty cycle of the CLK-OUT signal is maintained at 50%. The charge and discharge rates are adjusted in this manner by the magnitudes of the control voltages V_p and V_N , which control the impedance of the transistors 22, 32, respectively. As explained above, the negative feedback of the system 10 automatically adjusts the magnitudes of the V_p and V_N signals in this manner.

One embodiment of the integrator 18 is shown in Figure 4. The integrator 18 includes an inverter 50 formed by a PMOS transistor 52 coupled in series

with an NMOS transistor 54, with the gates of the transistors 52, 54 coupled to each other. The transistors 50, 52 are coupled in series with a current source 56 and a current sink 58 between a supply voltage V_{CC} and ground. An output node 60 of the inverter 50 is coupled to a capacitor 62 to supply the feedback voltage V_F .

5 In operation, when the CLK-OUT signal is low, the NMOS transistor 54 is turned OFF and the PMOS transistor 52 is turned ON to couple the current source 56 to the capacitor 62. The capacitor 62 is then charged linearly toward V_{CC} . When the CLK-OUT signal is high, the PMOS transistor 52 is turned OFF and the NMOS transistor 54 is turned ON to couple the capacitor 62 to the current sink 58. The
10 capacitor 62 is then discharged linearly toward ground. If the currents I_p and I_n are equal, then V_F will be constant only if the duty cycle is 50%. If the duty cycle is other than 50%, the signal V_F will charge to adjust the voltages V_P , V_N (Figure 2) until the duty cycle is 50%. Although one embodiment of the integrator 18 is shown in Figure 4, will be understood that a variety of integrator designs, both linear in the non-linear, as
15 well as other circuits may be used to provide a voltage indicative of the duty cycle of the CLK-OUT signal.

One embodiment of the transconductance amplifier 16 is shown in Figure 5. The transconductance amplifier 16 includes a pair of NMOS transistors 70, 72 that have their drains connected to each other and to ground through a constant
20 current sink 74, which draws a constant current I_C . The gate of the transistor 70 is coupled to receive the reference voltage V_{REF} while the gate of the other transistor 72 is coupled to the integrator 18 (Figures 1 and 4) to receive the feedback voltage V_F . Since the current sink 74 draws a constant current I_C , the sum of the currents through the transistors 70, 72 is constant. The transistors 72 thus passes a current I_1 while the
25 transistor 70 passes a current $I_C - I_1$.

In operation, when the feedback voltage V_F increases relative to the reference voltage V_{REF} , the current I_1 passing through the transistors 72 increases while the current $I_C - I_1$ passing through the transistors 70 decreases. Conversely, when the feedback voltage V_F decreases relative to the reference voltage V_{REF} , the current I_1
30 passing through the transistors 72 decreases while the current $I_C - I_1$ passing through the transistors 70 increases. Since the magnitude of the feedback voltage V_F is inversely

proportional to the duty cycle, the magnitude of the current I_1 is inversely proportional to the duty cycle.

One embodiment of the control circuit 14 (Figure 1) is illustrated in Figure 6. The control circuit 14 includes a first branch 80 and a second branch 82. The first branch 80 includes a single PMOS transistor 86 having its source connected to the supply voltage V_{CC} and its gate and drain coupled to each other and to the drain of the NMOS transistor 72 (Figure 5) and the gate of the NMOS transistor 22 (Figure 2). The PMOS transistor 86 is thus connected as a diode so that the current I_1 flowing through the transistor is directly proportional (but not necessarily linearly proportional) to the voltage across the transistor 86. As a result, the voltage V_p is inversely proportional to the current I_1 . Since the current I_1 is inversely proportional to the duty cycle, the magnitude of the voltage V_p is directly proportional to the duty cycle.

As the duty cycle increases, the increased magnitude of the voltage V_p decreases the current charging the capacitor 40 (Figure 2) thereby causing the input to the inverter 42 to increase to a voltage above the high transition voltage of the inverter 42 a later point in time. As a result, the duty cycle of the CLK-OUT signal is decreased. Conversely, as the duty cycle decreases, the decreased magnitude of the voltage V_p increases the current charging the capacitor 40 (Figure 2) thereby causing the input to the inverter 42 to increase to a voltage above the high transition voltage of the inverter 42 an earlier point in time. As a result, the duty cycle of the CLK-OUT signal is increased.

The second branch 82 includes a pair of PMOS transistors 90, 92 having their gates coupled to each other and to the drain of the transistor 90. The drain of the transistor 90 is also coupled to the drain of the NMOS transistor 70 (Figure 5). The transistors 90, 92 operate as a current mirror in which the current $I_C - I_1$ through the transistor 90 sets the source-to-drain voltage and the source-to-gate voltages of the transistor 90. However, since the gate of the transistor 90 is also coupled to the gate of the transistor 92, the current $I_C - I_1$ also sets the source-to-gate voltage of the transistor 92. Because both transistors 90, 92 have the same source-to-gate voltage, the current through the transistor 92 is the same as the current through the transistor 90, i.e., $I_C - I_1$.

The current flowing through the transistor 92 passes through an NMOS transistor 96, which has its gate and drain interconnected to form a diode. The voltage

V_N is thus proportional to the current $I_C - I_1$. Since the current I_1 is inversely proportional to the duty cycle, the current $I_C - I_1$ through the transistor 92 is directly proportional to the duty cycle. Therefore, the magnitude of the voltage V_N is directly (but not necessarily linearly) proportional to the duty cycle. As the duty cycle increases, the

5 increased magnitude of the voltage V_N increases the current discharging the capacitor 40 (Figure 2) thereby causing the input to the inverter 42 to decrease to a voltage below the low transition voltage of the inverter 42 an earlier point in time. As a result, the duty cycle of the CLK-OUT signal is decreased. Conversely, as the duty cycle decreases, the decreased magnitude of the voltage V_N decreases the current discharging

10 the capacitor 40 (Figure 2) thereby causing the input to the inverter 42 to decrease to a voltage below the low transition voltage of the inverter 42 a later point in time. As a result, the duty cycle of the CLK-OUT signal is increased.

In summary, an increase in the duty cycle of the CLK-OUT signal causes the integrator 18 (Figure 4) to reduce the magnitude of the feedback voltage V_F .

15 The reduced magnitude of the feedback voltage V_F causes the transconductance amplifier 16 (Figure 5) to reduce the current I_1 and increase the current $I_C - I_1$. The reduced current I_1 causes the magnitude of the voltage V_P to increase, and the increased current $I_C - I_1$ causes the magnitude of the voltage V_N to increase. With reference to Figure 2, the increased magnitude of the voltages V_P , V_N decrease the charge rate and

20 increase the discharge rate of the capacitor 40. As a result, the percentage of time that the capacitor 40 remains discharged to a voltage below the high transition voltage of the inverter 42 increases. The duty cycle of the signal CLK-OUT is thus decreased.

A decrease in the duty cycle of the CLK-OUT signal causes the integrator 18 (Figure 4) to increase the magnitude of the feedback voltage V_F . The

25 increased magnitude of the feedback voltage V_F causes the transconductance amplifier 16 (Figure 5) to increase the current I_1 and decrease the current $I_C - I_1$, thereby causing the magnitude of the voltages V_P and V_N to decrease. The increased magnitude of the voltages V_P , V_N increase the charge rate and decrease the discharge rate of the capacitor 40. As a result, the percentage of time that the capacitor 40 remains charged to a

30 voltage above the low transition voltage of the inverter 42 increases. The duty cycle of the signal CLK-OUT is thus increased.

An advantageous property of the control circuit 14 operating combination with the duty cycle adjustment circuit 12 is its good immunity from variations in the power supply voltage V_{CC} or ground potential. With reference to Figures 2 and 4, the magnitude of the control signal V_P is equal to the power supply voltage V_{CC} less the threshold voltage of the transistor 86. Although, as explained above, the threshold voltage is a function of the current I_1 , variations in the supply voltage V_{CC} are coupled to directly to the gate of the PMOS transistor 22 (Figure 2). However, when the transistor 20 is turned ON, the voltage on the source at the transistor 22 is equal to the supply voltage V_{CC} . Therefore, the voltages on both the gate and the source of the transistor 22 vary with the supply voltage V_{CC} so that the source-to-gate voltage of the transistor 22 is constant despite variations in the supply voltage V_{CC} . Similarly, variations in the supply voltage V_{CC} are coupled to the gates of the transistors 90, 92. However, since the voltage on the source of the transistor 92 also varies with V_{CC} , the source-to-gate of voltage of the transistor 92 is insensitive to variations in the supply voltage V_{CC} . The current flowing through the transistor 96 is thus constant despite variations in the supply voltage V_{CC} .

During the discharge of the capacitor, variations in the ground potential are more critical than variations in the supply voltage V_{CC} because variations in ground potential may affect the rate at which the capacitor 40 is discharged. However, variations in ground potential are coupled to the control voltage V_N in the same manner that variations in the supply voltage V_{CC} are coupled to the control signal V_P . Since the source of the NMOS transistor 32 is also at ground potential, the source-to-gate voltage of the transistor 32 is constant despite variations in ground potential. As a result, the charge and discharge rates of the capacitor 40 are insensitive to variations in the supply voltages, *i.e.*, V_{CC} and ground.

Although the duty cycle correction system 10 may be used in a variety of devices, it is shown in Figure 7 as part of a synchronous dynamic random access memory 110 ("SDRAM"). The SDRAM 110 includes a control logic circuit 114, an address decoder 116, and a read/write circuit 118, all of which are coupled to a memory array 120. As is well known in the art, the address decoder 116 receives an address over an address 1bus 22 and provides a decoded address to the memory array 120 to select an individual memory cell in the memory array. The read/write circuit 118

operates to receive data over a data bus 124 and provide that data to the memory array 120 during a write operation, and to provide data from the memory array to the data bus during a read operation.

The SDRAM 110 performs data transfer operations under control of the control logic circuit 114 which receives data transfer commands, including read or write commands, over a control bus 126. In response to these data transfer commands, the control logic circuit 114 executes each of the steps required to perform a read or write data transfer operation. The SDRAM 110 also receives a CLK to control the timing of various operations. The CLK signal may have a duty cycle that varies from a desired value, such as 50%. As a result, the CLK is applied to the duty cycle correction system 18 to generate the CLK-ADJ signal. The control logic circuit 114 executes each of the requisite steps synchronously, with the timing of each step being established relative to a rising edge of the adjusted clock signal CLK-ADJ. A clock enable signal CKE enables the clocking of the control logic circuit 114 by the adjusted clock signal CLK-ADJ.

Figure 8 shows a computer system 200 containing the SDRAM 110 of Figure 7 using the duty cycle correction system 18 of Figure 1. The computer system 200 includes a processor 202 for performing various computing functions, such as executing specific software to perform specific calculations or tasks. The processor 202 includes a processor bus 204 that normally includes an address bus, a control bus, and a data bus. In addition, the computer system 200 includes one or more input devices 214, such as a keyboard or a mouse, coupled to the processor 202 to allow an operator to interface with the computer system 200. Typically, the computer system 200 also includes one or more output devices 216 coupled to the processor 202, such output devices typically being a printer or a video terminal. One or more data storage devices 218 are also typically coupled to the processor 202 to allow the processor 202 to store data in or retrieve data from internal or external storage media (not shown). Examples of typical storage devices 218 include hard and floppy disks, tape cassettes, and compact disk read-only memories (CD-ROMs). The processor 202 is also typically coupled to cache memory 226, which is usually static random access memory ("SRAM") and to the SDRAM 110 through a memory controller 230. The memory controller 230 normally includes a control bus 236 and an address bus 238 that are

coupled to the SDRAM 110. A data bus 240 may be coupled to the processor bus 204 either directly (as shown), through the memory controller 230, or by some other means.

From the foregoing it will be appreciated that, although specific embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the invention. For example, the functions performed by the components shown in Figure 1 may be combined so that they are performed by a fewer number of components or expanded so that they are performed by a greater number of components. Additionally, a variety of circuits may be used in place of the circuits shown in Figures 2 and 4-6. Accordingly, the invention is not limited except as by the appended claims.